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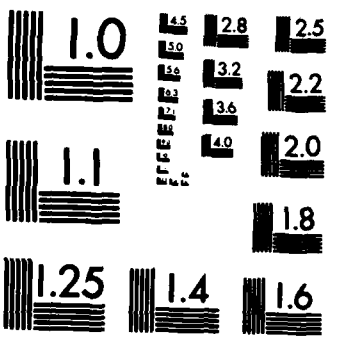

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TECHNICAL REPORT NO. 14

PICOSECOND X-RAY GENERATION FROM PICOSECOND PHOTOELECTRON PULSES

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ABSTRACT

An x-ray source capable of producing picosecond range pulse widths at high repetition rates is demonstrated. Picosecond light pulses are converted to picosecond electron pulses which are then accelerated onto a target to produce x-rays. Using a conventional PIN diode, a time duration of less than 300 psec is observed for Al K_α x-ray emission. This x-ray source has potential applications for fast dynamic measurements of light-induced structural changes and for characterizing picosecond x-ray diagnostic equipment.

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The advent of high brightness, short temporal width x-ray emission from synchrotron radiation and from laser-produced plasmas has led to the use of x-rays as a probe for kinetic studies. Dynamic measurements on the millisecond to subnanosecond time scale have been demonstrated, with current emphasis placed on resolving structural changes in biological samples.[1-7] Unfortunately, the temporal width of synchrotron radiation is limited by the characteristics of the particle accelerator,[1,3,6] and the complexity of the equipment involved precludes its easy replication. Laser generated plasma emission suffers both from the high energy per pulse requirement which restricts it to low repetition rate lasers, and from the collisional plasma heating time which sets a lower limit to the temporal width,[8-11] although these restrictions might be somewhat eased by using the two pulse technique developed by Epstein et al.[12]

We report here on a simple, low cost means of producing a high-repetition rate, characteristic x-ray emitting source capable of temporal widths down to the picosecond time scale. Using an extension of earlier work done with picosecond electron diffraction,[13] this technique involves the generation of picosecond pulses of photoelectrons which are rapidly accelerated in a high electric field and then strike an anode-target where they produce x-rays. It has been previously noted in another context that x-rays can be generated from photoelectrons in the presence of high electric fields.[14,15] We now show that photoelectron pulses can be used to generate short x-ray bursts.

The x-ray generator shown in Fig. 1(a) consists of a flat metallic photocathode held at a large negative voltage with respect to the grounded flat anode, which also serves as the x-ray source. A metallic photocathode is used instead of the more efficient alkali halide materials so that the apparatus can function at moderate vacuum and later be opened to air. Gold is a particularly good choice in this respect as it is virtually free of oxide layers which would reduce the photoelectric efficiency. For the typical 5×10^{-5} Torr vacuum, the maximum applied voltage at the 2 cm electrode spacing is 25 kV.

The light source is the fourth harmonic of an actively-passively mode-locked Nd/YAG laser producing 15 psec pulses of approximately 10 mJ at the laser fundamental or approximately 30 μJ at 266 nm following frequency conversion (measured with a Laser Precision RJ-700 energy meter). The yield and temporal profile of the photoelectron and x-ray bursts are measured with a factory calibrated PIN diode operated at 290V DC near the breakdown voltage (Quantrad model 025 PIN-125 M). To measure the x-ray burst the diode is placed directly behind the anode-target, with a 25 μm or 50 μm Beryllium window to block the incident

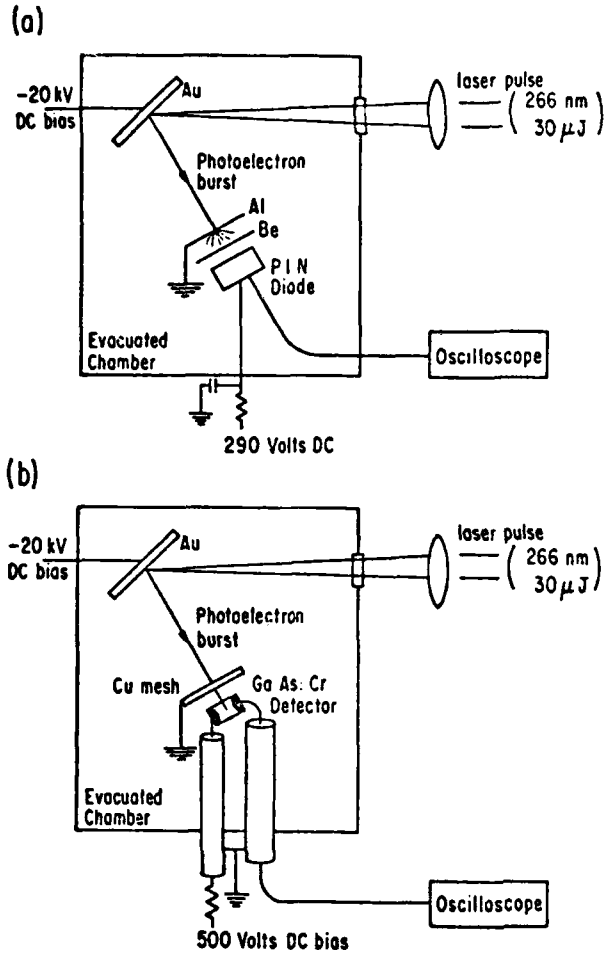

FIG. 1. *Schematic representation of the x-ray source and: (a) PIN diode detector; (b) Ga As: Cr doped picosecond detector.*

electrons and scattered laser light. Using a grounded copper mesh instead of the anode target, the electron burst is measured both with the PIN diode and with a Ga As detector developed at the Laboratory for Laser Energetics,[16] as shown in Fig. 1(b). Both detectors are coupled by 20 GHz semi-rigid coaxial cable to a fast oscilloscope (Tektronix model 7104 with time base 7B92A and vertical amplifier 7A29). By direct irradiation of the Ga As detector with 15 psec 266 nm laser pulses, the response of the oscilloscope is found to be approximately 250 psec.

Based on the process of electron beam conductivity, the Ga As detector can be used to measure the photoelectron pulse width and the result is shown in Fig. 2. The oscilloscope limited response of ~ 250 psec indicates that the photoelectron pulse width is on the order of the 15 psec laser pulse. It was, however, not possible to measure the x-ray emission with the Ga As detector.

The temporal profile of the x-ray burst is measured with the PIN diode and the observed signal with a 10-90% risetime of approximately 400 psec is shown in Fig. 3. The x-rays are generated from a 3 μm aluminum anode held at 20 kV with respect to the gold photocathode and are then filtered by a 25 μm Be window. To insure that the observed signal is not due to laser light or to transmitted electrons, the diode output has been checked in the absence of either laser light or high voltage. Both control conditions exhibit a random 10 mV peak-to-peak noise similar to that shown on the bottom trace of Fig. 3. Although it was not possible to fully calibrate the temporal response of the PIN diode,[17] deconvoluting the ~ 250 psec oscilloscope response from the observed x-ray signal indicates that the combination of the x-ray pulse width and the PIN diode response is ~ 300 psec.

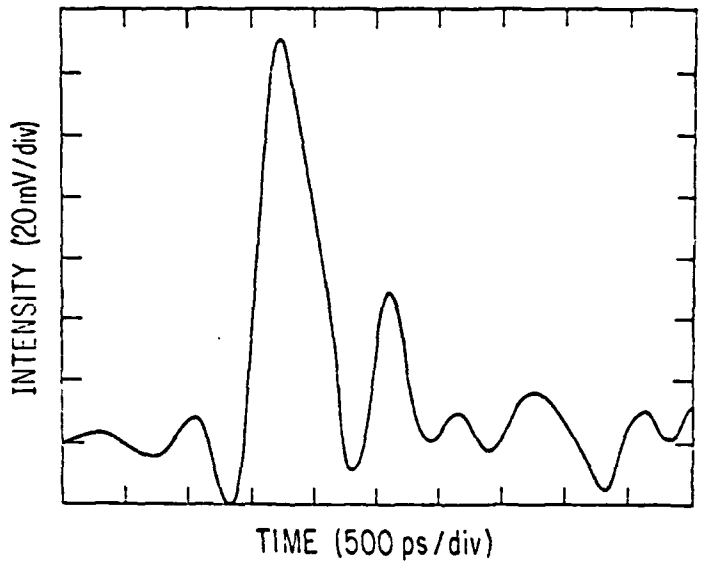

FIG. 2. *Trace of the oscilloscope limited response to the photoelectron burst measured with a Ga As detector. The input laser energy at 266 nm is approximately 30 μJ and the accelerating potential between the gold photocathode and the grounded copper mesh in front of the detector is 15kV. The 10 - 90 % risetime is ~ 250 psec.*

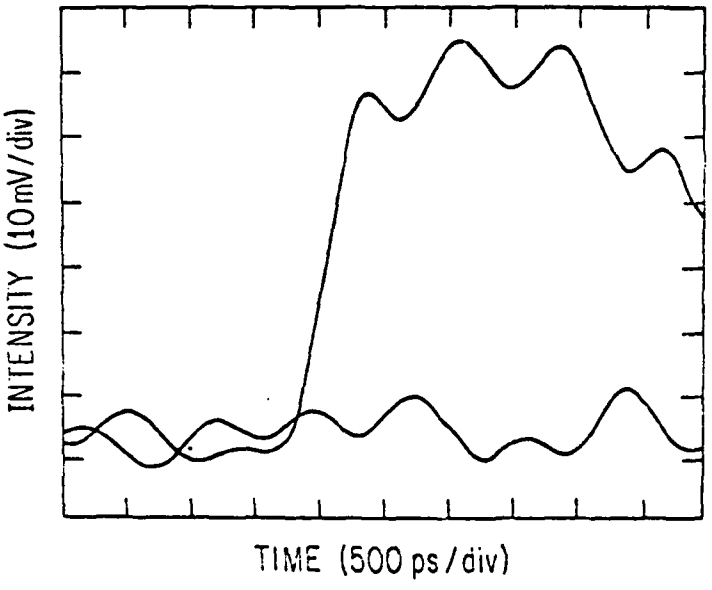

FIG. 3. Oscilloscope trace of the PIN diode signal from a 25 μm Be filtered burst of x-rays generated from a 3 μm aluminum anode held at 20 kV with respect to the gold photocathode. The laser input energy at 266 nm is ~ 40 μJ, the measured x-ray flux is 3×10^5 into $\sim 2\pi$ steradians and the signal risetime is ~ 400 psec. The bottom trace is taken with the laser light blocked and shows the random 10 mV peak-to-peak background.

The yield of photoelectrons and of subsequent x-rays is determined from the calibration curves of the PIN diode, and shows a linear dependence with input laser energy.[18] Under typical operating conditions, a 30 μJ pulse at 266 nm focussed to a spot size of 100 μm yields 10^7 electrons for an efficiency of approximately 10^{-6}. The yield of x-rays from electrons, measured in $\sim 2\pi$ steradian transmission through the 3 μm Al target and a 50 μm Be window, is approximately 1% for 20 kV accelerating potential. The observed factor of two drop in intensity in x-ray signal upon going from a 25 μm to a 50 μm Be window is taken as good evidence that the detected emission is indeed Al K_α line emission.[19]

Space charge broadening imposes important current density limitations on the photoelectron burst, which translate into a maximum of number of x-ray photons for a given temporal pulse width and spot size. Although durations of the observed signals are detector limited, we

believe that, due to space charge broadening,[20] the electron (and also the x-ray) bursts are longer than the initiating 15 psec laser pulse. In light of extensive studies in electron gun[20] and streak camera[21,22] development, one can expect that an optimized design comprised of a large, curved photocathode having a high accelerating potential and a short drift region will considerably increase the maximum x-ray yield. Further work with a picosecond x-ray streak camera may more fully characterize this technique.

The feature that distinguishes the photoelectron generation of x-rays from the more common plasma or synchrotron sources is the possibility of producing very short pulses of x-rays at high repetition rates from modest input powers using comparatively simple equipment. The efficiency of the photoelectric emission can be improved by several orders of magnitude by choosing a high yield, visible light photocathode, making it possible to operate this x-ray source with low power, high repetition rate lasers (such as mode-locked Argon ion lasers). Since the x-ray bursts are well synchronized with the laser pulses, such a system would provide an attractive source of low power, high repetition rate, short x-ray probe pulses for fast dynamic measurements, using transient x-ray diffraction[23,24] or absorption. A more immediate use for the short x-ray bursts would be to characterize picosecond x-ray diagnostic equipment.

In conclusion, an alternative source for x-ray line emission capable of operating at high repetition rates with picosecond range pulse widths is demonstrated by the use of photoelectron emission in high static electric fields. A pulse width of less than 300 psec is determined for the Al K_α x-ray emission. Optimization of source geometry and of photocathode material should provide a well-synchronized, low energy probe pulse for transient diffraction or absorption studies down to the picosecond time scale to follow light-induced structural changes.

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